This Plan which was developed under direction of the State Water Resources Board over the past 10 years, is intended to be a guide and master blueprint for future water development in California. I am certain that you will agree that in studies that were as comprehensive as these necessarily were, the problems of providing water for all the conceivable purposes which would arise in a state as diverse as California were faced many times. It is interesting to note, from operational studies of The California Water Plan, the effects of comprehensive ultimate development upon the present operation of some of our existing reservoirs. Take for instance the changes which would be possible in the present operational procedures of Shasta Reservoir on the Sacramento River in the event that a major reservoir were constructed downstream. With such a reservoir in existence, Shasta Reservoir could be operated more efficiently than at present. For example, a portion of the flood control space could be transferred to the downstream reservoir thus permitting the maintenance of higher reservoir levels in Shasta with obviously greater conservation and power benefits. Similarly, any large reservoir constructed on a major tributary of the Sacramento River would permit further improvement in the operation of existing reservoirs with consequent benefits creditable to the new works in weighing their justification. This may constitute an important factor in determining the feasibility of future water development projects.

The necessity for considering all presently known factors and requirements in the operation of the multipurpose reservoir have been pointed out as have a number of practices which hold promise for the future. We have also pointed out that the accumulation of the years of experience will be of great benefit in multipurpose reservoir operation. In addition, we have pointed out the beneficial effect which full basin development is going to have on all present and future multipurpose reservoirs and their operation. There is one final principle which is going to work to our advantage and which will be discussed in a subsequent paper so I will only briefly point it out. In early studies of The California Water Plan, it was demonstrated that there is not enough physical reservoir capacity which can economically be constructed in California's Central Valley to satisfy all the multi-requirements for water regulation. Consequently, in the future, a much greater dependence is going to have to be placed upon the vast underground reservoir which exists in the alluvium of the Central Valley. A number of studies were made to determine if the necessary regulation of water supplies could be obtained in the underground reservoir. These studies indicate that it can, even under most conservative assumptions. Operation of this underground reservoir in conjunction with the surface reservoirs will enable us to make, and in many instances will require, striking changes in the present operation procedures and in present theory of operation of surface reservoirs. The combined effect will be an enhancement and fulfillment of all the basin needs for regulation of water.

WATERSHED MANAGEMENT AND WATER YIELD

by

Robert H. Burgy[1]

Watershed management is a term which has been used to describe many processes applied to watersheds. In its broadest sense watershed management may embrace the wide variety of management programs from the control of the area for the production of minerals, livestock, forage, timber, for recreation and certainly for water production. In the western United States as in all arid areas of the earth this latter consideration has been of principle concern. It is to the matter of the management of certain of our water-producing lands that this discussion will be devoted.

A brief look at the hydrologic cycle will reveal certain basic facts which must be considered in any study of the disposal of precipitation on a watershed. Precipitation falling on a typical watershed is disposed of in several ways; as direct runoff, indirect runoff, accretion to groundwater and soil moisture, or through loss to the atmosphere by evaporation. In each of these categories there are numerous subdivisions. If the principal interest is in the management of watersheds for the production of water and increased water yields, then the management must take

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a form which will modify the proportion of the precipitation channeling into each of these.

It is obvious, however, that if a management program is to be of greatest benefit, it must permit increases in water yield without deleterious effects. Perhaps the most practical method of modifying disposal of precipitation on the watershed is through the management of the vegetation. This does not, however, preclude certain programs which have been used in some areas to produce optimum or maximum water yields through complete paving of the soil surface.

Manipulation of vegetation as a form of watershed management has long been of interest in the field of hydrology. Numerous experiments have been conducted to determine the responses of watersheds subjected to various treatments. It is, I believe, quite clear at this time that the manipulation of vegetation will result in marked changes in precipitation disposal factors. Removal of the primary intercepting vegetative canopy permits a greater amount of precipitation to reach the soil surface. This item alone must result in a greater contribution of water from the area since for a given set of conditions of soils, geology, vegetation and climate the balance will have been disturbed. Furthermore, the removal of vegetation in many cases will result in a modification of the soil surface, the governing agent in infiltration. Within the limits of practicality it is impossible for man to affect a modification of the actual soil capacity for retaining moisture. Thus, increased runoff must be the anticipated result of manipulation of the vegetation on watersheds where precipitation is sufficient to satisfy soil moisture capacities. The actual method of vegetative manipulation is also important in determining the ultimate response.

As was noted earlier, management must produce a beneficial response in increased water yield without undesirable effects. It would be wonderful indeed to be able to simply modify the vegetation on a watershed and obtain increases in water yields. Unfortunately, this is not generally the case. The increased runoff occasioned by the additional precipitation arriving at the soil surface and contributing to a greater quantity of surface and sub-surface runoff may create situations of increased movement of debris down channels. In those cases where infiltration rates have been modified, further increases in surface runoff may cause higher erosion rates.

Recognizing these principles, we of the University have been engaged in studies for some time in an attempt to develop vegetative manipulation programs to avoid the undesirable aspects and to take advantage of those desirable ones. Within the state of California there are several major zones of vegetation on our mountain watersheds. These are generally described as the woodland grass areas at the lowest elevation in the foothills; the chaparral or brushlands lying in the intermediate elevations; and the forested lands at the upper reaches of the watersheds. It is within the second zone that a considerable amount of research has been centered.

Some 13,000,000 acres in this state are so situated with regard to climate and topography that they might well be considered as potential range lands to be used in the production of forage for livestock. Broad programs have been developed in attempts to control the undesirable chaparral growth on these areas and to substitute desirable forage species. Such procedures have been referred to as range management or improvement programs. These potential range lands which are being subjected to management are extremely critical due to their location, lying as they do between the areas of use in the irrigated valleys, and the upper watershed.

The higher elevations usually receive a large portion of the precipitation in the form of snow which is retained in temporary storage until the melt season. This matter becomes of immediate concern to those involved in the estimation of water yields from snow pack areas. Stream flow records are frequently obtained at gaging stations located at the lower part of the watershed. Over long periods certain relationships between precipitation and runoff have been developed and correlated with the measurements made of the water content of the snowpack in the upper watersheds. When sufficient records are obtained fairly reliable forecasts can be made of the runoff to be anticipated in any given season. Needless to say, this is a very complicated procedure to develop, as is true of any system involving natural phenomena, and the results are subject to much error.

Considerable evidence has been gathered to indicate that marked changes in runoff characteristics may result from this management on the watershed. Failure to recognize this fact may introduce appreciable error in forecasts based upon stream flow records. The remainder of this discussion will be devoted to a discussion of the data accumulated from approximately 25 years of study of such brushland vegetation management programs.

The Department of Irrigation of the University of California initiated hydrologic studies of the effects of brushland conversions in about 1933. The earlier phases of the operation involved the use of small plots situated in typical brushlands of California. These plots were established in pairs one of which was immediately subjected to a complete vegetative removal process. The other of the pair was held as a climatic control or check plot. Some 40 pairs of these were established. Records of precipitation, runoff and erosion were collected continuously for approximately 10 years on each of the plots. The pairs were then reversed. The original treated plot was allowed to return to native vegetation and the brush-covered plot was converted to grass. In these early studies no attempt was made to revegetate the plots after removal of the brushy vegetation. Native grasses usually developed.

As the study progressed it became obvious that plots would not give a complete picture of the situation since they did not involve an entire unit in nature. Therefore, a series of small watersheds were established in the same general regions as the plots. These small watersheds consisted of pairs again. Because of the difficulty of locating two identical units in nature it was necessary to calibrate these watersheds to determine their relative characteristics. Calibration was established at approximately 5 years on the presumption that within the 5 year period a reasonable experience of weather phenomena might be expected. As it developed, however, longer calibrations were used in the earlier studies. On both the plots and the small watersheds soil moisture samples were taken at frequent intervals to determine the moisture relationships throughout the season. At the end of the calibration phase of this study, one of the pair of watersheds was selected for treatment. These treatments generally consisted of the removal of the native brushy vegetation and the substitution of an improved grass-type cover.

Further experience again indicated that larger watershed units than those selected initially were necessary. There are several factors which enter into the selection of the most desirable size of watershed to study in such a program. One major concern is the cost of developing the equipment necessary to make the measurements. In this study erosion measurements were made by actual sedimentation of the debris coming down the channel of the stream. This debris is weighed out after each storm. The stream gaging stations used in conjunction with these sedimentation basins incorporated standard hydraulic measuring devices to avoid calibration difficulties and to permit as high a level of accuracy of measurement as was possible. In some cases volumetric measuring devices as well as weirs or flumes were used.

The largest complete watershed unit which has been developed thus far is approximately 200 acres in area. The sedimentation basin required for this watershed has a capacity of about 1/3 acre foot per debris storage. Larger watersheds have been included but these do not have debris measuring devices.

It might be noted here that the use of other sediment measuring devices such as aliquot samplers may be more economical and possibly more desirable since the labor required to service a sedimentation basin becomes appreciable. Devices of this type are being considered at the present time and may be incorporated in some of the existing structures to test the various types.

Table I describes some of the characteristics of the several watersheds now under study.

The vegetation management processes applied to these watersheds were designed to insure a complete treatment and to maximize the severity of the treatment. Certain preparatory steps were used. These involved the slashing of the vegetation early in the summer season, the slashed brush being allowed to dry on the ground for as long as possible before the application of fire to the area. Fire was used on all of the studies except one. Use of fire is indicated on this type of land cover as being the most economical means of removal of the vegetation. This preparation of the vegetation results in a much more severe treatment than would be possible otherwise. After the treatment had been applied studies were continued for a minimum of three years. This three-year minimum period is necessary to allow for a complete conversion from the brushy species to a new cover. The revegetation process was accomplished by reseeding the areas with grass species indicated by agronomic studies in these regions conducted by the University.

As of this date we have under study seven major watershed installations involving either single watershed complexes or pairs. These are located from Shasta County on the north to Tulare County on the south, in both the foothills of the Coast Ranges and Sierra Nevada mountains, as shown in Table 1. Five of these areas have been subjected to vegetation management treatments. On three of the areas the treatment has been in effect for a period of over three years. On the fourth the vegetation was removed in the fall of 1956 so only one season's record has now been gathered, and on the fifth the vegetation was removed over a period of about 1 1/2 seasons and involved a somewhat different type of vegetation management, the stripping of vegetation by means of mechanical equipment. As noted earlier, it is necessary to have several years of record

Table I. Small Watershed Studies Location and Description of Areas

Station	County	Major Stream Watershed	Watershed Area	Vegetative Type	Elev-ation	Soil Series	Ave. Soil Depth	Season Started	Date of Treatment	Type of Treatment
			Acres		Ft.		Ft.			
Ono	Shasta	N. Fork of								
A		Cottonwood Crk.	0.91	Chamise	1500	Aiken	2-3	1939-40	Fall 1949	Burned
B			0.47	Chamise	"	Aiken	2-3		—	
C			0.62	Chamise	"	Aiken	2-3		—	
D			0.66	Chamise	"	Aiken	2-3		Fall 1949	Burned
Diamond Range										
A	Tehama	Cottonwood Crk.	5.32	(Oak, Pine,	1000	Corning	3-4	42-3	Fall 1953	—
B*			2.74.	(Chaparral	1000					Slashed & burned
Ahawahnee										
A*	Madera	Fresno R.	3.08	(Mixed	3000	Holland	3-4	47-8	Fall 1953	Slashed & burned
B			3.80	(Chaparral	3000					—
Badger										
A*	Tulare	Cottonwood Crk.	12.2	(Mixed (	2900	Holland	3-4	49-50	54-56 (completed Fall '56)	Bulldozed & burned
B		of Kings R.	15.4	(Chaparral	2700					—
Placer										
A	Placer	Doty Crk.	60	Oak, grass	800	Aiken	2-4	56-7		—
B		of Feather R.	50		800	(Variation)				—
C			20		800					—
Hopland										
Ia*	Mendocino	Russian R.	43	(Mixed	1000		1-6	52-3		Slashed & burned
IIa		" "	213	(Chaparral	650	Laughlin				—
Mariposa										
A	Mariposa	Piney Creek	4000	(Mixed	1800	Aiken	1-4	52-3		—
B		of Merced R.	2000	(Chaparral	1200	(Variation)				—

* Denotes the treated watershed of the pair.

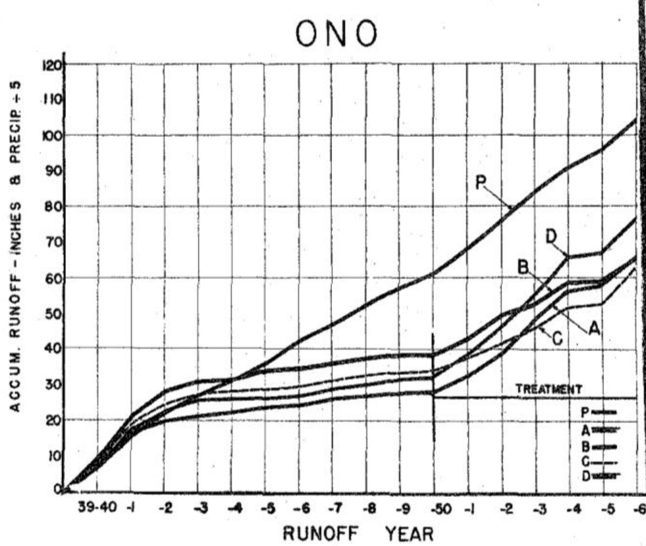

Fig. 1. Mass Curve of Seasonal Runoff, Ono Watershed

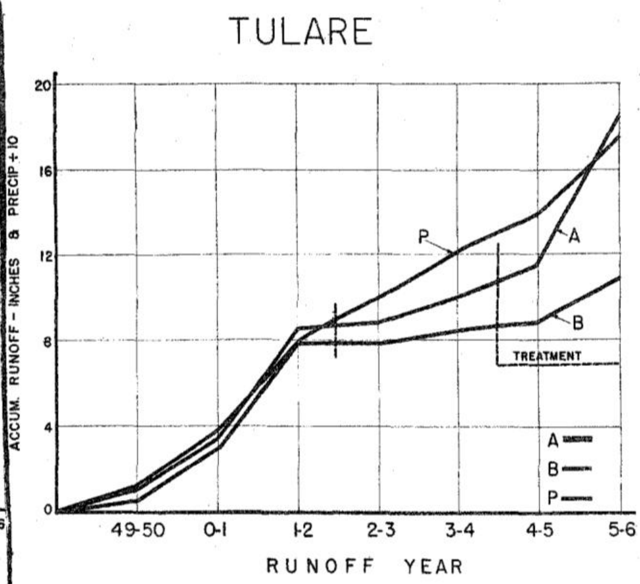

Fig. 2. Mass Curve of Seasonal Runoff, Tulare Watershed

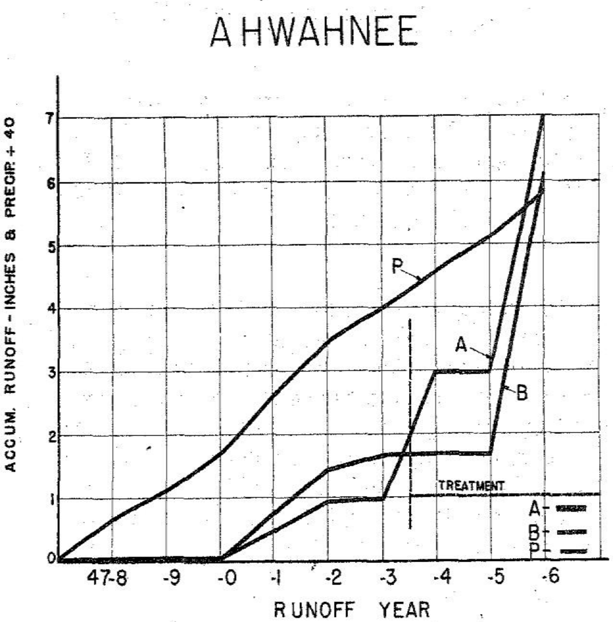

Fig. 3. Mass Curve of Seasonal Runoff, Ahwahnee Watershed

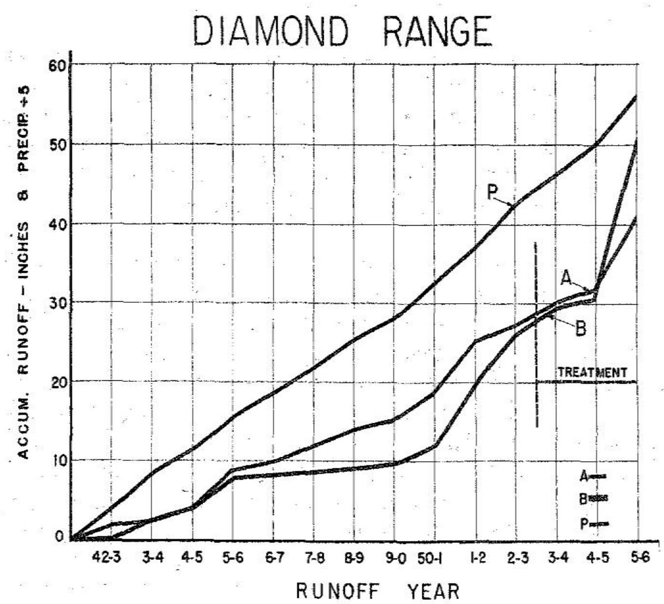

Fig. 4. Mass Curve of Seasonal Runoff, Diamond Range

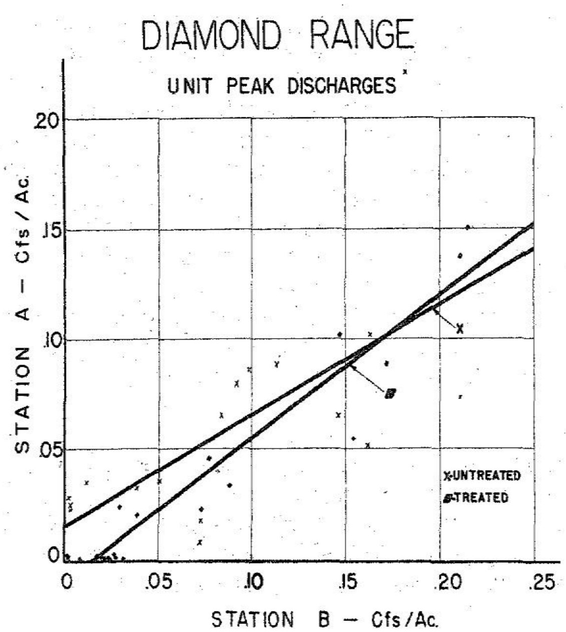

Fig. 5. Unit Peak Discharges, Diamond Range, Before and After Treatment

after treatment to permit rational analysis. Therefore, only those which have been operated through several seasons will be considered here and additionally we will concern ourselves only with aspects of the hydrologic studies which might be of interest to you as snow runoff forecasters. There are numerous other aspects of this work that are of interest to hydrologists and these are being considered elsewhere.

The use of mass-curves of runoff have been chosen as being a simple and straightforward method of presenting the relationships between pairs of very small watersheds, one of which has been treated. Figures 1 through 4 show the relationship between cumulative runoff in inches for the several seasons of operation. The cumulative precipitation curve has also been shown on the graphs to indicate the variation in seasonal precipitation. In all of these cases the time of the treatment is indicated on the graph.

The longest period of record is represented by the Ono watersheds. From this record we may observe that for the treated watersheds, A and D, the curves lie below the adjacent B and C curves prior to the accomplishment of the treatment. However, after treatment a reversal takes place and the D watershed particularly will be observed to show a marked increase in total seasonal runoff. Watershed A also indicates an increase in runoff by coming into position two in descending order at the end of the record. It will be noted from the graph that runoff increased in all cases on the mass curves but that for the two treated watersheds the increases are significantly higher during the post-treatment period, even for those years of extremely low rainfall. This indicates that the vegetation management process has caused an increase in water yield or runoff even during the lowest of rainfall years.

The Tulare record, Figure 2, shows relatively comparable runoff up to the 1952-53 season. Thereafter the A watershed begins to advance more rapidly. The actual treatment on Tulare watershed A was accomplished during the 1955-56 season and yet you will note a slight increase in earlier record. This perhaps may be explained by the fact that wide firebreaks were cut around these watersheds. Due to the shape of watershed A the firebreak evidently had some influence on the runoff even though the entire drainage had not been manipulated.

Figure 3 for the Ahwahnee Stations in Madera County represents another condition wherein the runoff during the season immediately following the vegetation management was sharply increased on A as opposed to zero runoff on B. Precipitation during the 1953-54 season was normal for this area. During the 1954-55, however, precipitation was somewhat below normal which resulted in zero runoff from both watersheds. In the succeeding 1955-56 season which was notable in California the runoff from both A and B was appreciable but with the greater quantity coming off of the B watershed. Because of the previous runoff the total for the total record is greater for the A watershed. This leads us to the conclusion that during periods of extremely high precipitation and for long duration storms, the influence of man on the earth's surface is relatively negligible. That is to say that vegetation management effects are completely obscured and masked out by the excesses of runoff which occur. This effect has been observed and is being given careful study. It should be also noted here that the B watershed at Ahwahnee is approximately twice as large as A which may also account for an increased total seasonal value.

The final curve is that of Diamond Range located in Tehama County. At Diamond Range the record begins with the 1942-43 season and progresses on upward with the B watershed data well below that of the A record up to the time of treatment. This treatment was accomplished in the 1953-54 season and it will be noted that the B data immediately responded with a slight increase in runoff. This increase was not noted in the 1954-55 season which was well below normal precipitation. However, in the 1955-56 season again a large increase in runoff is indicated on the graph.

From an interpretation of these graphs I must conclude that some definite response results from vegetation management on these typical brush covered watersheds. The whys of this response in increased water yield have been discussed earlier and are undoubtedly related to the removal of the intercepting canopy and possibly changes in the surface of the soil. Certainly the soil, the geographical location of the study area, and the character of the storms producing the runoff all have a profound influence upon the responses of these watersheds. During those seasons immediately following treatments when normal or greater than normal precipitation was experienced very positive increases in runoff were noted from the treated watersheds. During periods of lower precipitation this initial response is noted in some cases. On all of the watersheds the areas are very small and the character of the gaging stations is such as to preclude the measurement of the entire outflow from these drainages. These data represent principally surface runoff.

This is important since none of the subsurface contributions from the watersheds could be measured. Could the entire outflow of the basins have been measured we might well expect to find even greater increases in runoff both during and after the storm period.

To test the effect of the treatment on peak discharges, unit discharges were computed for these flows and were plotted as ordinate and abscissa on a graph of A versus B discharges in second-feet per acre. This is shown for the Diamond Range watershed in Tehama County in Figure 5. The locus of the points indicate that a slight increase in unit discharges has been effected by the treatment. This has not been the case in all of the study areas.

It appears evident from these considerations that vegetation management may have a significant effect upon the runoff characteristics of watershed so treated. The data available at the present time are only for small watersheds ranging in size from less than one to approximately twenty acres. Current studies include watersheds up to 4,000 acres in area which will, we believe, give a more realistic picture of the situation since the larger areas will permit the inclusion of all runoff and not just the surface components. As was suggested earlier the scope of vegetation manipulation for watershed management is rapidly developing. Should this program become of large enough scale to include major portions of stream systems, it will be necessary to recognize these facts in the utilization of streamflow records. Further studies along these lines are now under way and will be continued in an effort to isolate in great detail the effects of various watershed management practices on the hydrologic characteristics.

MAXIMIZING RIVER BASIN BENEFITS BY CONJUNCTIVE OPERATION OF SURFACE AND GROUND-WATER RESERVOIRS

by

Frank B. Clendenen[1]

Much has been said about the great conflict of reservoir purposes in water resources development. This is due primarily to the competition among these purposes for the limited storage capacity. Students of water resources development are familiar with the difficult proposition of affording flood control along with conservation, power generation, and recreation on a storage scarce stream. Flood control desires empty reservoirs while the interests of the other three purposes require the opposite; a highly paradoxical situation. The solution has taken the form of a compromise with the calculation of an operation schedule to maximize the benefits of the reservoir. Thus an operation schedule with a variation in flood control reservation with time, thereby releasing such reservation for conservation wholly or partially when the dangerous season is past, is the usual compromise on California Sierra streams. From a second examination of these four principal purposes of western water resources development it is apparent that actually, if sufficient storage were available, these purposes are not at odds. Conservation desires the control of all waters for beneficial use, flood control desires the control of all peak flows and is fully satisfied if they can all be detained in storage; hydroelectric power generation favors full reservoirs for scheduled release; and recreation interests are best served by increased water surface area of reservoirs and firmed minimum flows in streams. These all are benefited by storage of water. This is an obvious point; yet at times in the planner's quandary over proper allocation of existing or proposed storage capacity he seems to forget this point.

Storage capacity being in large part the solution to problems of water resources development, it behooves the developer for the future to inventory water storage capacity and requirements to determine proper planning for future development. In California this immense task has been performed by the California Department of Water Resources. The future requirements for water have been compiled and presented in State Water Resources Board Bulletin No. 2 and the inventory of

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